Coherent Microwave Cherenkov Radiation

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Overview

- Introduction to Cherenkov radiation
- Coherent visible Cherenkov radiation
- Microwave Cherenkov radiation
- Coherent microwave beam tests at SLAC
- Askaryan effect in electromagnetic showers
- Neutrino astronomy using Cherenkov radiation - IceCube
- Neutrino astronomy using coherent microwave Cherenkov radiation – Arianna
- ATF studies

Cherenkov Radiation

Nothing travels faster than light … in vacuum.

In matter, with an index of refraction, n,
there is a threshold velocity, $\beta_t = v_t/c = 1/n$,

When charged particles travel faster than β_t they emit EM radiation, so they glow.

Angle of radiation depends on the velocity, β, of the charged particle:

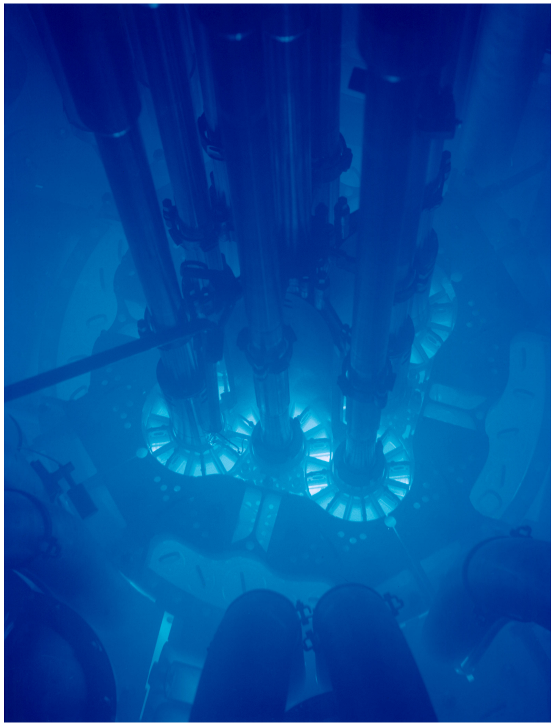
$$\cos\theta = 1/(n\beta)$$

So at threshold, $\theta = 0$ degrees.

Visible Cherenkov Radiation

When many particles emit CR, they can glow brightly.

CR from a reactor core: Electrons from nuclear decay emit CR in water.



The CR spectrum is largest at visible wavelengths, scaling like:

$$\frac{d^2N}{dx d\lambda} = \frac{2\pi\alpha z^2}{\lambda^2}\left(1 - \frac{1}{\beta^2 n^2(\lambda)}\right)$$

Note dependence on z^2.

Microwave Cherenkov Radiation

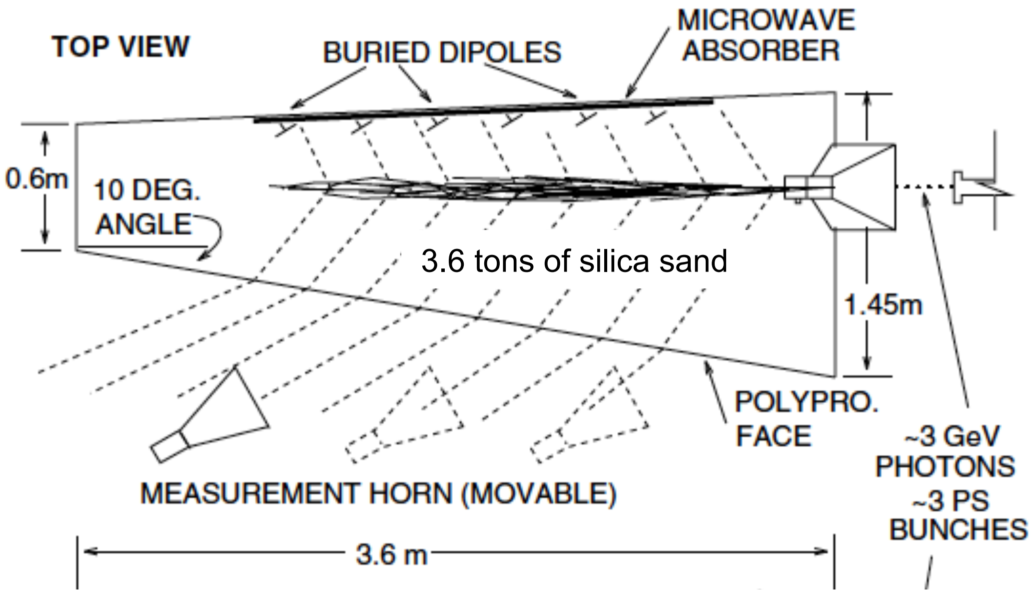
At frequencies of ~1 GHz, λ = 30cm, so the CR intensity is reduced by a factor of 10^{-5} compared to visible CR (when integrated over the acceptance of an antenna).

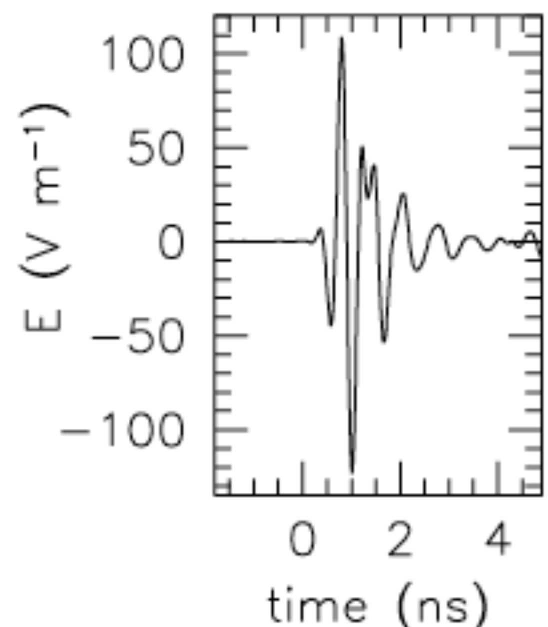
However, because the wavelength of the microwaves is so long, CR from multiple sources can add coherently to produce very large signal strength.

A bunch of 10^9 electrons (~nC) shorter than 30 cm will radiate microwaves coherently with an intensity that is 10^{18} times stronger than a single electron.

SLAC Measurement

First observation (SLAC 2001) made use of Askaryan§ effect where EM showers develop a 20-30% electron excess due to positron annihilation and Compton scattering.



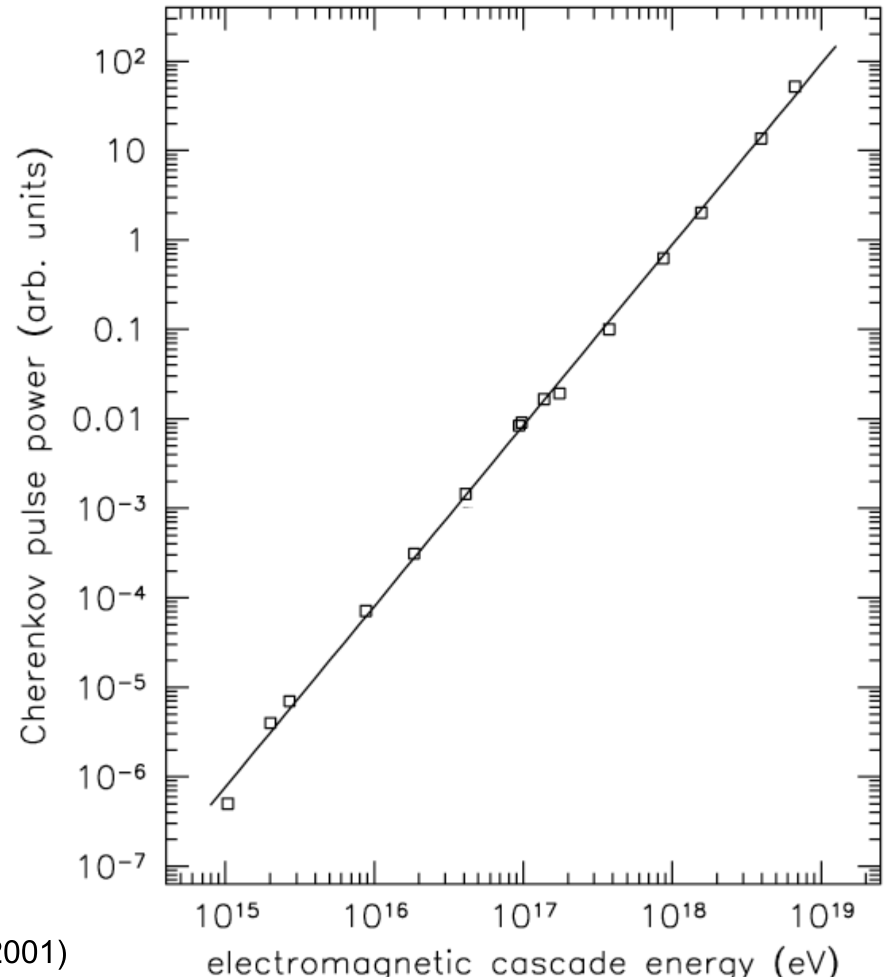


§G. Askaryan, Sov. Phys. JETP **14**, 441 (1962); **21** 658 (1965)

Evidence of Coherence

As EM shower energy increases, the electric field strength increases.

CR power is proportional to E^{α} with α = 1.92 ± 0.1, showing complete coherence of the CR.



From D. Saltzberg *et al*, PRL **86**, 2802 (2001)
P.W. Gorham *et al*, PRD **72**, 023002 (2005)

Application: Neutrino Astronomy

Compact sources of cosmic rays cannot be localized because of bending in the galactic and intergalactic magnetic fields.

High energy protons scatter off CMB producing pions (GZK cutoff).

High energy photons are suppressed due to scattering and pair production off the intergalactic medium.

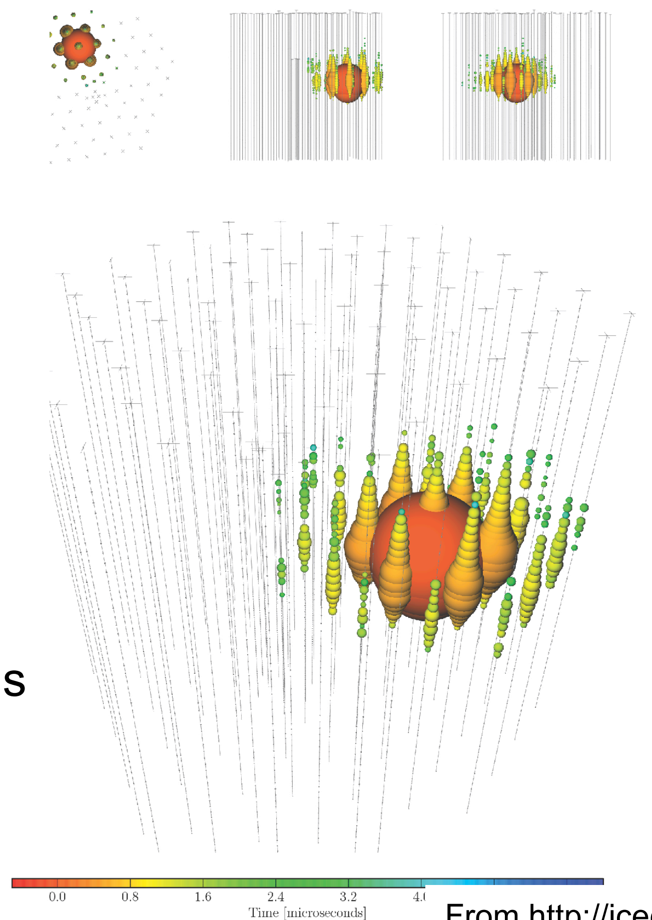
Only neutrinos can preserve high energies and directionality of source.

Detection is the problem!

Neutrino Astronomy: Ice Cube

Visible Cherenkov radiation is used by the IceCube Collaboration to measure the energy of cosmic ray neutrinos at the South Pole Neutrino Observatory. They have instrumented a cubic kilometer of ice with PMTs to look at EM showers produced when neutrinos interact in the ice.

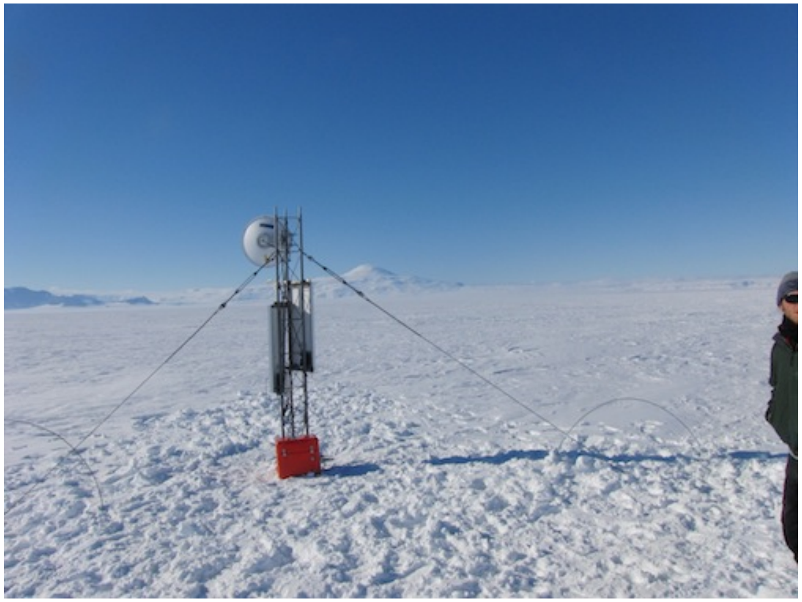
This neutrino deposited an estimated 1141 TeV of energy in the Antarctic ice, observed via the Cherenkov radiation produced by the electrons and positrons in the EM shower.



From http://icecube.wisc.edu

Neutrino Astronomy: Arianna

Microwave Cherenkov radiation is used by the Arianna Collaboration to measure the energy of cosmic ray neutrinos at the South Pole Neutrino Observatory. They will instrument a 100 km^3 of ice with radio antennae to look at EM showers produced when neutrinos interact in the ice. Ultimately they hope to deploy 1296 antenna for a neutrino detection rate that is 1-2 orders of magnitude greater than IceCube.



From http://arianna.ps.uci.edu

Currently Arianna has instrumented 7 radio detector stations, Hexagonal Radio Array (HRA-7), and has seen no evidence for cosmic neutrinos.

Preliminary Studies at the ATF

Install a log-periodic Yagi antenna in the ATF 50 MeV electron beam, mounted on a rotational axis in the vacuum chamber.

Look for coherent microwave Cherenkov radiation produced when the short electron bunches impact the various targets in the vacuum chamber.

Check quadratic dependence on beam intensity.
Check angular sensitivity.
Check polarization.
Explore different target materials.

Summary

Coherent Microwave Cherenkov Radiation observed at SLAC photon beam via Askaryan effect (2005).

Ready to test non-Askaryan effect Coherent Microwave Cherenkov Radiation at the ATF.

Development of detectors for Coherent Microwave Cherenkov Radiation will be useful for cosmic ray experiments and high energy neutrino detectors.

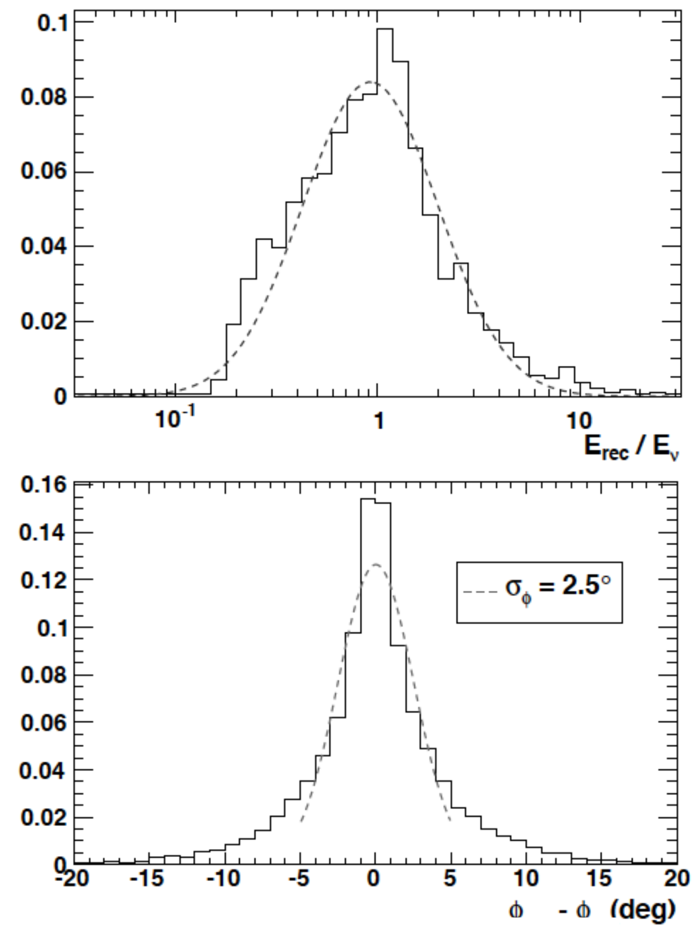
Additional Slides

Neutrino Astronomy: Arianna

Simulated performance of the Arianna detector with 1296 antennae:

Energy resolution is $\sigma(E_{rec}/E\nu) = 2.2$

Pointing resolution (with polarization measurement) $\sigma(\phi) = 2.5$ degrees.

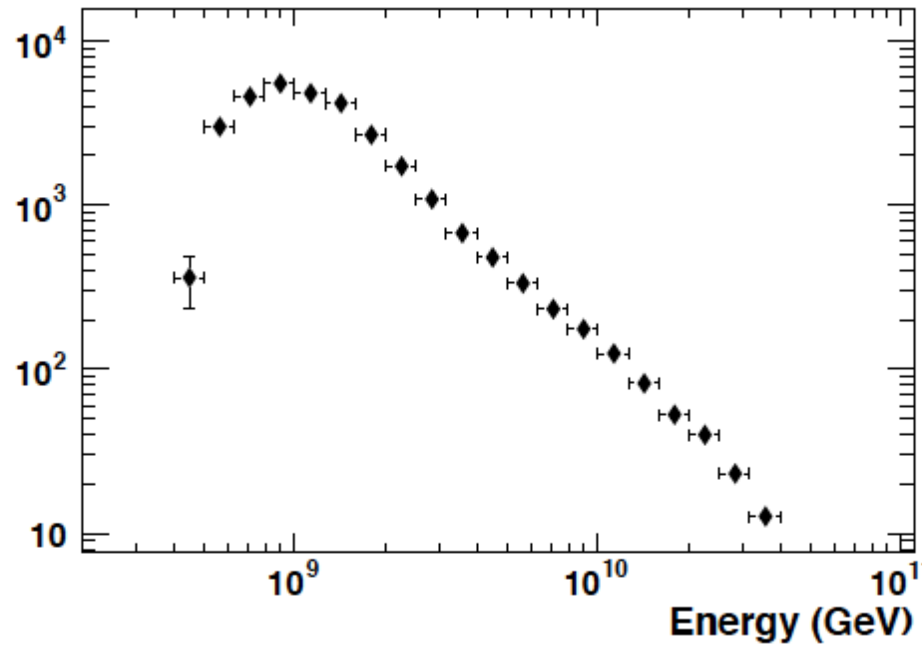


ARIANNA Collaboration, S.W. Barwick *et al*, arXiv:14410.7352v1, to be published in Astroparticle Physics)

Neutrino Astronomy: Arianna

Simulated performance of the Arianna detector with 1296 antennae:

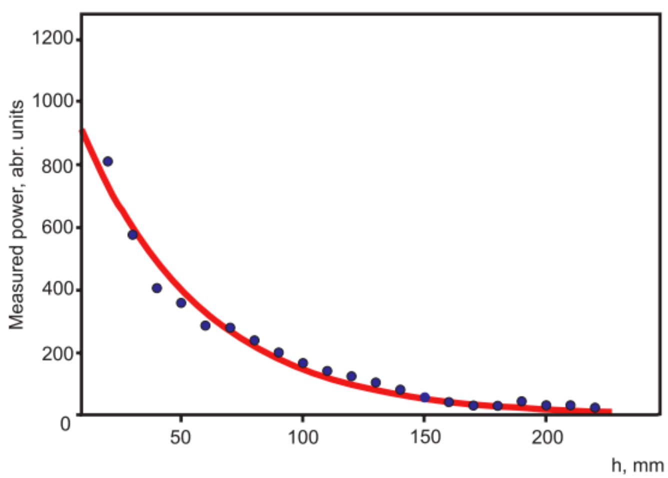
Expected flux of neutrino candidates as a function of neutrino energy for a one-year Arianna run.

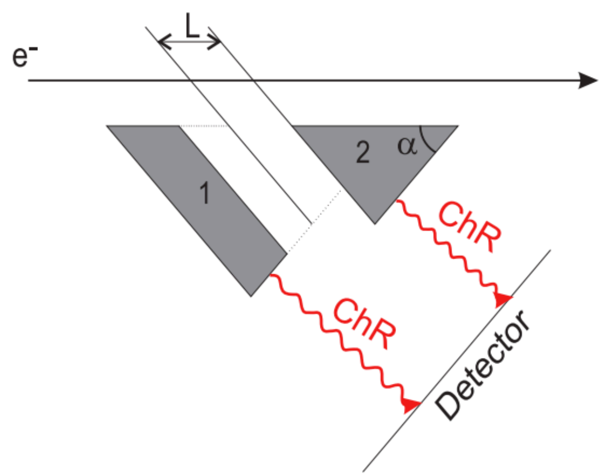


ARIANNA Collaboration, ibid.

Other applications

Coherent Cherenkov radiation has been used as a diagnostic to measure bunch lengths for short electron beam bunches nondestructively. Beam does not pass through radiator (CsI). Constructive interference for L < bunch length





From M.V. Shevelev *et al*, Il Nuovo Cimento 34, 297 (2011)